Mineral Composition of Feathers

from Canada Geese (*Branta canadensis*) Fed Experimental Diets

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Pictured on the cover are a pair of giant Canada geese (female on the left, male on the right) photographed at Fort Totten, Devil's Lake, North Dakota, by Harold C. Hanson.

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Mineral Composition of Feathers from Canada Geese (*Branta canadensis*) Fed Experimental Diets

Robert L. Jones, Eugene L. Ziegler, and Harold C. Hanson

Abstract

To investigate interrelationships between diet and the mineral content of primary feathers, Canada geese (*Branta canadensis*) were trapped in February 1969 at Union County Refuge, Illinois, held in individual cages at Urbana, Illinois, and provided diets containing Ca, Mg, Na, and Fe in a 2^4 factorial experiment. Two sequential growths of primary feathers were sampled for these minerals. Results confirmed that diet is the key factor in determining mineral profiles of feathers but also illustrated the difficulties in interpreting the mineral content of feathers in relation to the nutritional ecology of wild geese. The findings generally validate the technique employed by Hanson and Jones (1968, 1976) in which the mineral profiles of feathers were used to identify the colonies of origin of blue and snow geese.

Introduction

The determination of natal origins of wild geese from the mineral content of their primary feathers is a technique of immense potential in goose management. In effect, primary feathers from a given goose can serve to identify its origin and thereby provide important information not heretofore available; similarly, feathers can document the origins of populations that have not been conventionally banded. The accuracy of "feather prints" is based on the fact that no two geographical areas are alike with respect to rock substrate, soils, and elemental concentrations of the nutrient chain expressed in food plants. The mineral profiles of feathers reflect these relationships. Thus, Hanson and Jones (1968, 1976) correctly classified the natal origins of 70–85 percent of the individuals in samples of blue and snow geese (*Anser c. caerulescens*) from four breeding colonies. This degree of accuracy is high, especially because colonies of blue and snow geese are associated with braided river mouths or coastal areas that have rather small differences in the geochemistry and mineralogy of their soils and soil parent materials. Another notable example of how feathers can serve as biological tracers was the correct reclassification to natal area of 95 percent of the giant Canada geese (*Branta canadensis maxima*) nesting either in the Playgreen–Kiskito lakes region of central Manitoba or in the Rennie population of southeast Manitoba (Hanson et al. 1982). Because both populations winter in Wisconsin, knowledge of their origins is important if birds of known origin are to be harvested and if flock population dynamics are to be monitored.

The mineral profiles of feathers also provide insight into the interrelationships of minerals in physiological systems. Copper, for example, has been found at significantly higher levels in adult female Ross' geese (*Anser rossii*) than in adult males (Hanson and Jones 1974). These higher levels were attributed to hormonal influences and were apparently requisite for the egg-laying cycle. Although these findings conform with those of other physiological studies, Kelsall et al. (1975a) found reverse sex-related differences in Cu levels in the primary feathers of snow geese collected at the northwest corner of the MacKenzie River Delta, Northwest Territories. Although not directly relevant to the present study, Kelsall et al. (1975b) found significant interspecific differences in the chemical content of the primaries of penned mallards (*Anas platyrhynchos*), black ducks (*A. rubripes*), and lesser scaup (*Aythya affinis*) given the same rations. Part of these differences may be explained by the differential ingestion of food particles because the bill morphology of ducks and their methods of feeding vary widely (Goodman and Fisher 1962).

Finally, Edwards and Smith (1984) found that the mineral profiles of primary feathers were modified through physical adsorption phenomena when Canada geese were exposed to new and chemically different environments, a finding anticipated by Hanson and Jones (1976:11). In spite of these modifications, however, the fundamental differences associated with dietary influences specific to natal areas were not obscured.

The present study evaluates the main effects and interactions of dietary Ca, Mg, Na, and Fe on concentrations of these elements in feathers. A main effect is the effect of an independent variable, which in this study was one of the four mineral elements in the diet, on a dependent variable, which in this study was a mineral element in the feather. An interaction, on the other hand, refers to a situation in which the effect of an independent variable on a dependent variable

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is determined by the values of one or more other independent variables. Given the diverse bedrock types available to geese and the differences in their access to brackish water, these four mineral nutrients are expected to vary widely in diets of geese on natal and moulting areas. Our earlier work (Hanson and Jones 1976) found substantial correlations among certain pairs of elements in keratin and suggested interactions at the level of incorporation in keratin. The experiment described here tested for interactions among Ca, Mg, Na, and Fe and for the main effects of these elements at two levels in the ration.

Methods

Thirty-nine yearling male Canada geese were selected from birds trapped in February 1969 at Union County Wildlife Management Area, Illinois. In retrospect, we recognize that this sample probably included several of the seven races of Canada geese now known to breed in the Hudson Bay Lowland and migrate down the Mississippi Valley Flyway (Hanson, unpublished). We do not believe, however, that differences in mineral metabolism among races affected the mineral content of feathers. The geese were banded and randomly assigned to individual fiberglass cages at Urbana, Illinois.

Rations were prepared that contained Ca, Mg, Na, and Fe at two levels. The experiment was designed as a 2^4 factorial set of treatments with unequal replication. The number of geese randomly assigned to each treatment is given in Table 1. This design was a compromise between the number of cages and other resources available. Each 100 g of ration was compounded as 48 g glucose (Cerelose), 40 g soybean meal, 10 g corn oil, 0.3 g DL-methionine, 0.2 g choline chloride, and 0.1 g mixed vitamins. The remainder of the diet was a salt mixture that supplied essential macroelements and trace elements and was adjusted to give two levels of Ca, Mg, Na, and Fe. Sodium was added as NaCl to provide levels of 0.4 or 0.8 g. Calcium was added as $CaCO_3$ and $CaHPO_4 \cdot 2H_2O$ (in the ratio 2.3 to 1 based on Ca content) to provide levels of 0.45 or 0.90 g. Magnesium was added as $MgSO_4 \cdot H_2O$ to provide levels of 0.05 or 0.10 g. Iron was added as $FeSO_4 \cdot 7H_2O$ to provide levels of 0.03 or 0.06 g.

The geese were allowed 30 days to adjust to the cage environment, and the experiment began on 15 April with the pulling of primary feathers from both wings of each bird and the introduction of the experimental diet. The first sample of newly grown primaries was collected on 10 June. Four geese had died during the adjustment period, and 28 of the remaining 35 birds had grown primaries suitable for sampling (Table 1). A second growth of primaries was sampled on 27 August with the following exceptions: two earlier samples taken on 17 August, and five later samples (one on 5 September and four on 16 September) of slower growing primaries or primaries that had been delayed in beginning growth. Thirty-two birds continuing into the second phase of the experiment provided these feather samples (Table 1).

TABLE 1. Average mineral contents ($\mu g\ g^{-1}$) by treatment for two serial samplings of primary feathers grown by geese on diets with different levels of Ca, Mg, Na, and Fe.

Treatment and Level[a]					First Feather Sample					Second Feather Sample				
n[b]	Ca	Mg	Na	Fe	n[c]	Ca	Mg	Na	Fe	n[c]	Ca	Mg	Na	Fe
3	1	1	1	1	1	475	121	116	77	2	736	192	140	208
2	1	1	1	2	1	583	154	51	142	1	1480	225	40	644
3	1	1	2	1	2	437	114	140	72	2	777	288	286	104
2	1	1	2	2	2	502	170	110	184	1	849	207	58	59
2	1	2	1	1	1	614	162	140	91	2	714	172	74	147
3	1	2	1	2	2	422	132	150	196	3	887	138	83	263
3	1	2	2	1	3	572	159	180	859	3	844	218	267	385
2	1	2	2	2	1	615	132	139	1894	1	998	216	172	595
2	2	1	1	1	2	484	112	186	118	2	620	148	52	120
3	2	1	1	2	3	505	149	103	125	2	750	187	126	322
3	2	1	2	1	2	669	140	454	1140	3	905	235	497	372
2	2	1	2	2	1	594	152	131	181	1	940	181	172	199
2	2	2	1	1	2	733	147	134	992	2	808	164	172	329
2	2	2	1	2	2	448	128	152	114	2	661	167	84	159
2	2	2	2	1	1	514	152	154	801	2	699	170	182	633
3	2	2	2	2	2	502	152	112	96	3	730	195	173	134

[a] 1 and 2 refer to lower and higher mineral levels, respectively.
[b] Number of geese per treatment.
[c] Number of geese with feathers suitable for analysis.

Feathers were washed four times (1 hr each time) with distilled water and dried at 65°C. After vane material was cut from the shaft, it was redried, weighed, ashed at 500°C in a Vycor crucible, and dissolved in redistilled 6 M HCl. Calcium and Mg contents were determined by atomic absorption spectroscopy, Na by flame emission spectroscopy, and Fe by absorptiometric analysis using orthophenanthroline. All contents are presented as $\mu g\ g^{-1}$ of dry weight of vane.

During the design phase of the experiment, we recognized that robustness of analysis of higher order interactions would be lost because of the unbalanced design (H. W. Norton, Department of Animal Science, University of Illinois at Urbana-Champaign, personal communication). We selected the design, however, because of the differences among the four mineral elements found in our previous analyses of feathers from wild geese inhabiting ecosystems with diverse nutritional substrates and because we hoped to gain insight into interelemental relationships. Significant results would, of course, lead to more efficient designs for subsequent studies.

Data were analyzed by the Statistical Analysis System (SAS) general linear model (GLM) procedure (SAS Institute Inc. 1982). Hypotheses were tested at the $P \leq 0.05$ level using type III sums of squares. For effects that were significant, tables of least-squares means are presented to portray the nature of interactions on the element in question.

Results

The means for mineral contents of feathers taken from the geese after the acclimation period and after being fed experimental diets are presented in Table 2. Mean values for Mg (second sample) and Fe (both samples) in feathers grown by birds on experimental diets were similar to those in feathers taken from birds just after capture, a finding that suggests that these elements were available to the wild population in a nutritional pattern similar to that provided by the diets. Sodium was lower and Ca was higher in feathers grown in the wild than in feathers grown by birds on the experimental diets. If the content of a given element in feathers were in direct proportion to the level of that element ingested in an experimental diet and if no interactions occurred, these data would suggest that Ca was low and Na high in the experimental diet.

The average mineral contents of feathers from both samplings and for each of the 16 treatments are presented in Table 1. Five significant interactions were found wherein levels of two or more elements in the diet affected the concentration of an element in feathers. In three instances, one element in the diet significantly affected the level of another element in feathers, the phenomenon termed "main effect."

Effects on the Fe content of feathers. Only one significant effect, the interaction of diet Ca by Mg by Na on feather Fe, was common to both samplings (Table 3). In the first sampling, feather Fe was also

TABLE 2. Mean contents ($\mu g\ g^{-1}$) and standard errors for selected mineral elements in primary feathers taken from wild Canada geese following capture and in two subsequent samplings on 10 June and 27 August after the captive geese had been fed, beginning in late February, diets varying in Ca, Mg, Na, and Fe.

		Ca		Mg		Na		Fe	
	Number	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Wild Sample	35	1238	32	194	5	43	3	256	9
First Sample	28	501	26	142	5	159	20	248	47
Second Sample	32	747	25	192	10	179	27	246	36

TABLE 3. Least-squares mean Fe contents ($\mu g\ g^{-1}$) of two samplings of primary feathers from Canada geese. Within each feather sample field, contents not followed by the same letter are significantly ($P \leq 0.05$) different.

	First Feather Sample Diet Level				Second Feather Sample Diet Level			
	Low Mg		High Mg		Low Mg		High Mg	
Diet Level	Low Na	High Na	Low Na	High Na	Low Na	High Na	Low Na	High Na
Low Ca	110 b,c	128 b,c	144 b,c	1376 a	426 a	82 b	205 a,b	490 a
High Ca	121 c	660 b	553 b,c	449 b,c	221 a,b	285 a,b	244 a,b	99 b

significantly affected by the interaction of diet Ca by Fe (Table 4) and by diet Mg and diet Na main effects as discussed in the following paragraph. In the Ca by Mg by Na interaction of the first sampling, the high levels of Ca and Mg in the diet tended to be associated with increased feather Fe. The highest Fe level of both feather samplings, however, occurred with Mg and Na at their high diet levels and Ca at its low level. Feather Fe was substantially and significantly lowered in both samplings by increasing Ca in the diet when Mg and Na were at their high levels. The two-way interaction of Ca by Fe significantly affected the Fe content of feathers in the first sampling (Table 4). Increased Fe in the diet at the low Ca level significantly increased feather Fe; however, increased Fe in the diet at the high Ca level significantly lowered feather Fe. This effect of Ca may be operating in the large decreases in Fe in both samples in the Ca by Mg by Na interaction when each element was at its high diet level as noted above (Table 3).

Significant main effects of both diet Mg and Na on feather Fe occurred in the first sampling. The least-squares means were 255 and 232 ppm Fe at low levels of Mg and Na, respectively. At high diet levels of Mg and Na, feather Fe increased substantially to 630 and 653 ppm, respectively. Recall that Mg and Na were involved in a significant diet Ca by Mg by Na interaction on Fe, and thus the interpretation of individual direct effects of Mg and Na on Fe content is difficult. The stimulative effects of diet Na and Mg on feather Fe, however, suggest direct effects on feather Fe that are worthy of future investigation.

Effects on the Ca content of feathers. Feather Ca in the second sampling was significantly affected by the diet Ca by Mg by Na interaction (Table 5). The highest Ca content in feathers occurred when Ca, Mg, and Na were at low levels in the diet. Calcium concentration was significantly lowered by increasing dietary Ca in the diet when Mg and Na were at their low levels; Ca was also significantly lowered when the Mg content of the diet was raised in the presence of low Ca and low Na levels. The second lowest level of Ca in feathers, however, was associated with Ca, Mg, and Na at their high levels.

Effects on the Mg content of feathers. Diet Fe and Mg interacted to affect Mg content in feathers from the first sampling (Table 6). The highest Mg content occurred at low diet levels of Fe and Mg. Increasing Mg at both the low and high Fe levels reduced the Mg content of feathers, but the reduction was significant only at the low level of Fe.

Effects on the Na content of feathers. In a significant main effect, high dietary Fe lowered feather Na from 209 to 114 ppm in the second sampling. This finding, in view of the previously noted direct effect of diet Na on feather Fe in the first sampling, provides more evidence for mutual effects of dietary Fe and Na on feather composition.

Discussion

The results of this experiment may help to understand some of the mineral patterns observed by Hanson and Jones (1976) in the feathers of lesser snow geese. For example, the comparison of feathers from geese breeding at the mouth of the McConnell River, Northwest Territories, with feathers from geese breeding near Cape Henrietta Maria, Ontario, offers a contrast between ecosystems underlain by igneous and metamorphic rocks and those underlain by fine-grained calcareous sediments. In effect, the diet and feather data from these two wild populations constitute a natural experiment to which our data can now be compared. It should be pointed out, however, that the Canada geese in our study and the blue and snow geese in the "natural experiment" were not equally capable of responding to Na-rich environments. The

Table 4. Least-squares mean contents ($\mu g\ g^{-1}$) of Fe in primary feathers from Canada geese (first sampling). Contents not followed by the same letter are significantly ($P \leq 0.05$) different.

	Diet Level	
Diet Level	Low Ca	High Ca
Low Fe	274 b,c	604 a,b
High Fe	763 a	129 c

Table 5. Least-squares mean contents ($\mu g\ g^{-1}$) of Ca in primary feathers from Canada geese (second sampling). Contents not followed by the same letter are significantly ($P \leq 0.05$) different.

	Diet Level			
	Low Mg		High Mg	
Diet Level	Low Na	High Na	Low Na	High Na
Low Ca	1108 a	813 a,b	801 b	921 a,b
High Ca	685 b	922 a,b	734 a,b	715 b

Table 6. Least-squares mean contents ($\mu g\ g^{-1}$) of Mg in primary feathers from Canada geese (first sampling). Contents not followed by the same letter are significantly ($P \leq 0.05$) different.

	Diet Level	
Diet Level	Low Mg	High Mg
Low Fe	244 a	99 b
High Fe	152 a,b	138 b

coastal races of white-cheeked geese exploit Na-rich environments, but blue and snow geese shun these areas. The basis of this contrasting behavior is the lability of the supraorbital gland in Canada geese (Hanson and Jones 1976:188). Our observations indicate that blue and snow geese lack labile supraorbital glands, and this difference may complicate our comparison.

Data for Ca, Mg, Na, and Fe in feathers from the two colonies and for forages from carbonate and from igneous and metamorphic terranes are presented in Table 7. The forage sample for the latter bedrock type is from the McConnell River; the carbonate terrane sample is from Baffin Island, Cape Churchill, and Cape Henrietta Maria. The data for feathers were extracted from Table 26 in Hanson and Jones (1976) and the data for forage from Table 8 in the same publication. The higher Ca content of feathers from geese from Cape Henrietta Maria is not consistent with the significant interaction of diet Ca by Mg by Na (Table 5), an interaction that caused feather Ca to be highest when each of these elements was at its low diet level. Low levels for these three elements occur in forage from the igneous and metamorphic terrane, but feathers of McConnell River geese have lower Ca concentrations than those of Cape Henrietta Maria birds. Thus the contrast in feather Ca between these populations cannot be explained by our diet study.

The Mg content of feathers from Cape Henrietta Maria geese is lower (Table 7) than the Mg content in feathers from geese from the McConnell River colony, although Mg is probably higher in the forage of the Cape. This inverse relationship between feather Mg and diet Mg may reflect the interaction of diet Fe and Mg that resulted in the low feather Mg observed when diet Fe was at its low level and diet Mg at its high level (Table 6). Feather Na levels were similar for both colonies. The negative main effect of Fe on Na observed in our feeding study is not apparent if the average data for forages are representative for the colonies. Despite higher Fe forage levels from igneous and metamorphic terranes, feather Fe concentrations for the two colonies were similar. Feather Fe for the Cape Henrietta Maria colony may have been increased by the Ca by Mg by Na interaction (Table 3) to the level of the McConnell River colony. All three elements were higher in forage of carbonate terranes. In addition, the main effects of diet Na and diet Mg that increased feather Fe in our study can also explain the Fe content in feathers from Cape Henrietta Maria birds.

We speculate that interactions among mineral elements will occur in the diet of wild geese as a result of the ingestion of forages, the mineral contents of which are an ultimate response to soils that have been derived from different bedrock types and, in some cases, soils that have been affected to different degrees by inundation with saline waters. Much of the boreal and Arctic nesting grounds has also had a complicated history of late Pleistocene geologic events that affect soil chemistry and, therefore, the nutritional ecology of the region. Although these complex, mineral-nutrient interactions complicate interpretation, they also ensure that the feathers of geese from different areas have unique mineral patterns. More comprehensive feeding experiments will enable us to interpret, differentiate, and even predict the mineral patterns of feathers among wild bird populations. Eventually, field studies of the soils in areas used by wild goose populations, of the forage available in those areas, and of the mineral physiology of the wild geese themselves will place the study of feather minerals in a sound biogeochemical and physiological framework.

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TABLE 7. Contents ($\mu g\ g^{-1}$) of Ca, Mg, Na, and Fe in the primary feathers of snow and blue geese and in goose forages. Feather and forage samples are from areas of contrasting bedrock geology.

Sample type and sampling locality or terrane type	Ca	Mg	Na	Fe
Feather				
McConnell River	814 (24)[a]	436 (28)	330 (38)	274 (38)
Cape Henrietta Maria	1721 (24)	342 (24)	359 (46)	246 (24)
Forage				
Igneous and Metamorphic Terranes	3700 (6)	1600 (6)	328 (6)	937 (6)
Carbonate Terranes	6900 (14)	2400 (14)	981 (14)	472 (14)

[a] Number in sample.

omy, UIUC, and W. R. Edwards and G. C. Sanderson of the Illinois Natural History Survey. Personnel of the Illinois Department of Conservation at Union County Wildlife Management Area and G. C. Arthur, Illinois Department of Conservation, provided the geese used in this study and adapted them for release after the experiment. A. L. Evans, Department of Agronomy, UIUC, assisted in analyses of data. These findings are published with the permission of the Illinois Experiment Station, UIUC.

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